An Open Source Computational Geometry Library for Parametric Aircraft Design

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Outline

Introduction
- Aircraft design optimization
- TiGL Software overview

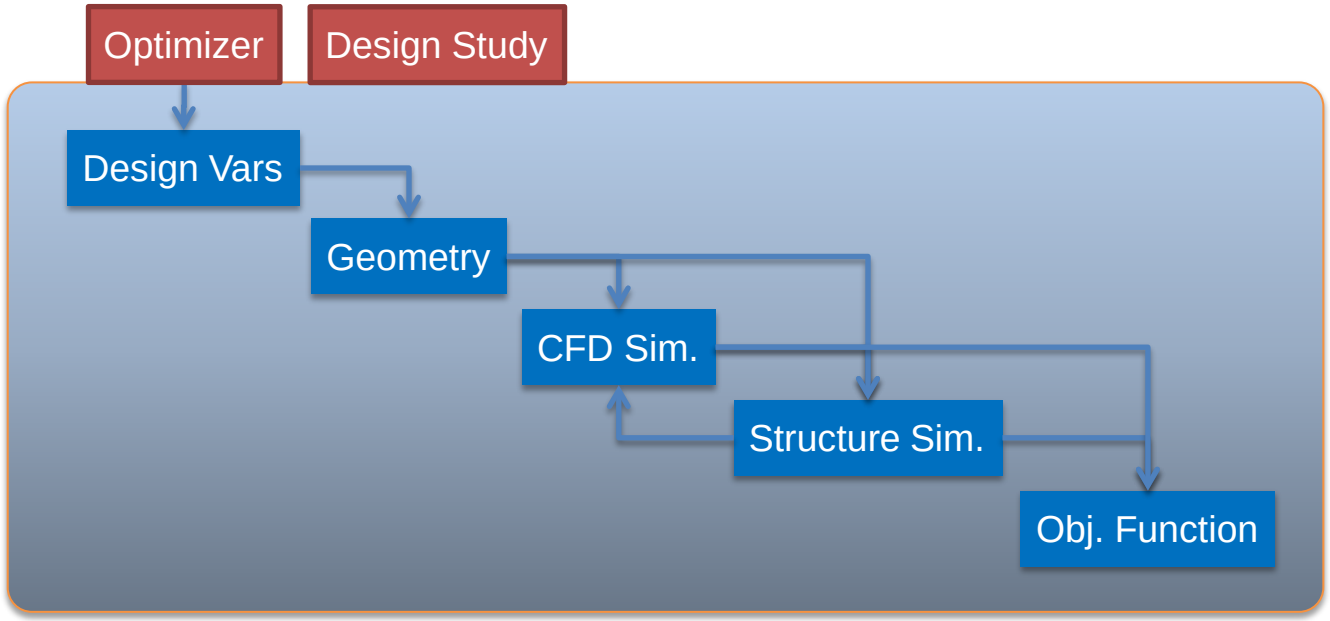
TiGL methods
- Applications and uses
- Architecture
- Curve and surface interpolation algorithms

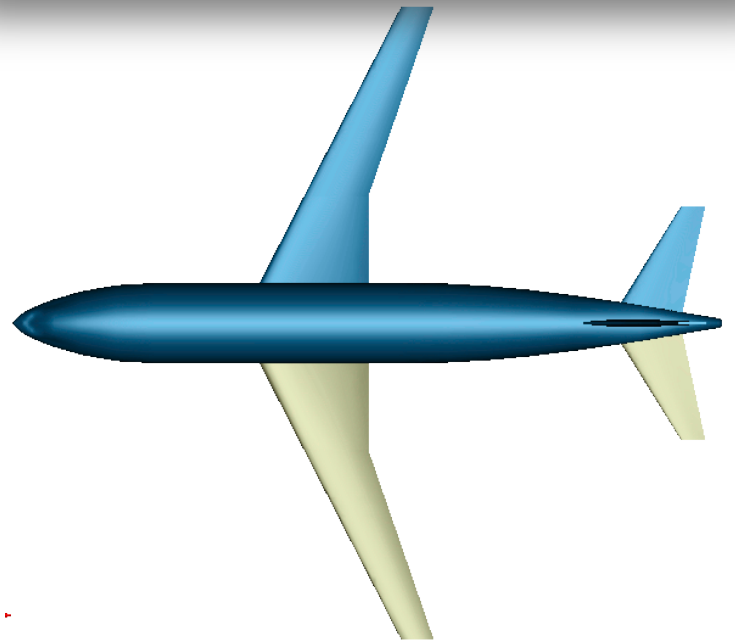
Results
- Comparison Gordon surfaces vs. Coons patches
- Complete aircraft geometries

Motivation

Aircraft design optimization overview

- Explore the aircraft of tomorrow
- Evaluate new designs

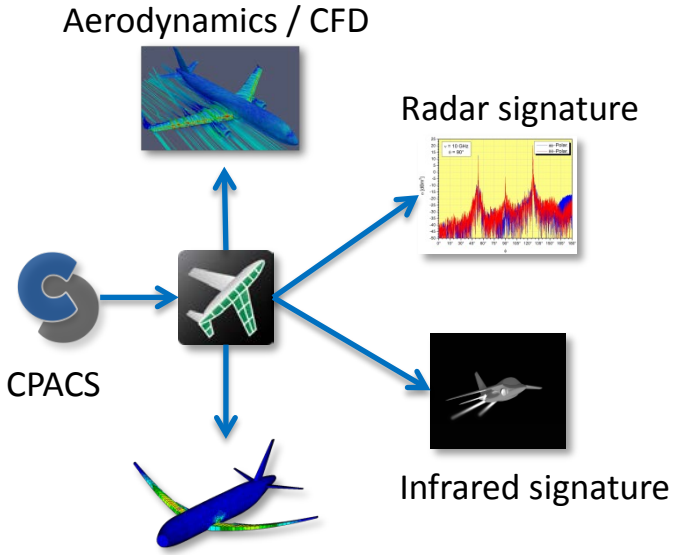


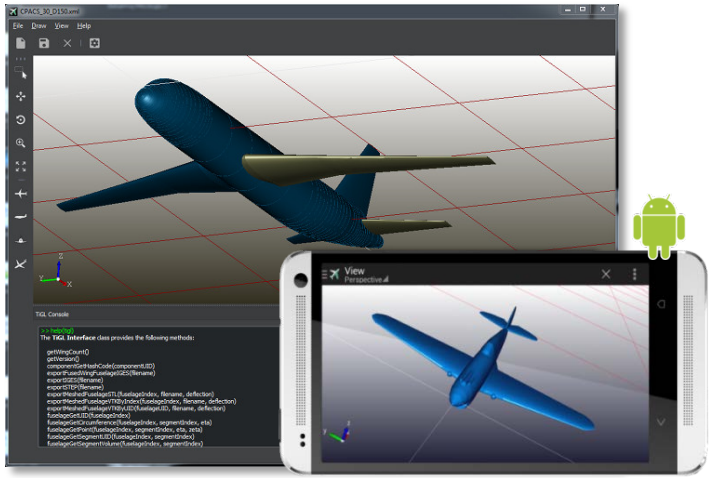


- Geometry generation has essential role
- All codes in the process chain must be robust

The TiGL software package

- C++ Library for parametric modelling of aircraft and helicopter based on parametric CPACS* (XML) files
- Used at DLR and international universities / research institutes for aircraft design and analysis
- TiGL Viewer to visualize CPACS-based aircraft geometries and other CAD files
- Cross platform: Linux, macOS, Windows, Android
- Open Source, developers from





*B. Nagel et. al., *Communication in Aircraft Design: Can we establish a Common Language?,* 28th ICAS, Brisbane, Australia, 2012

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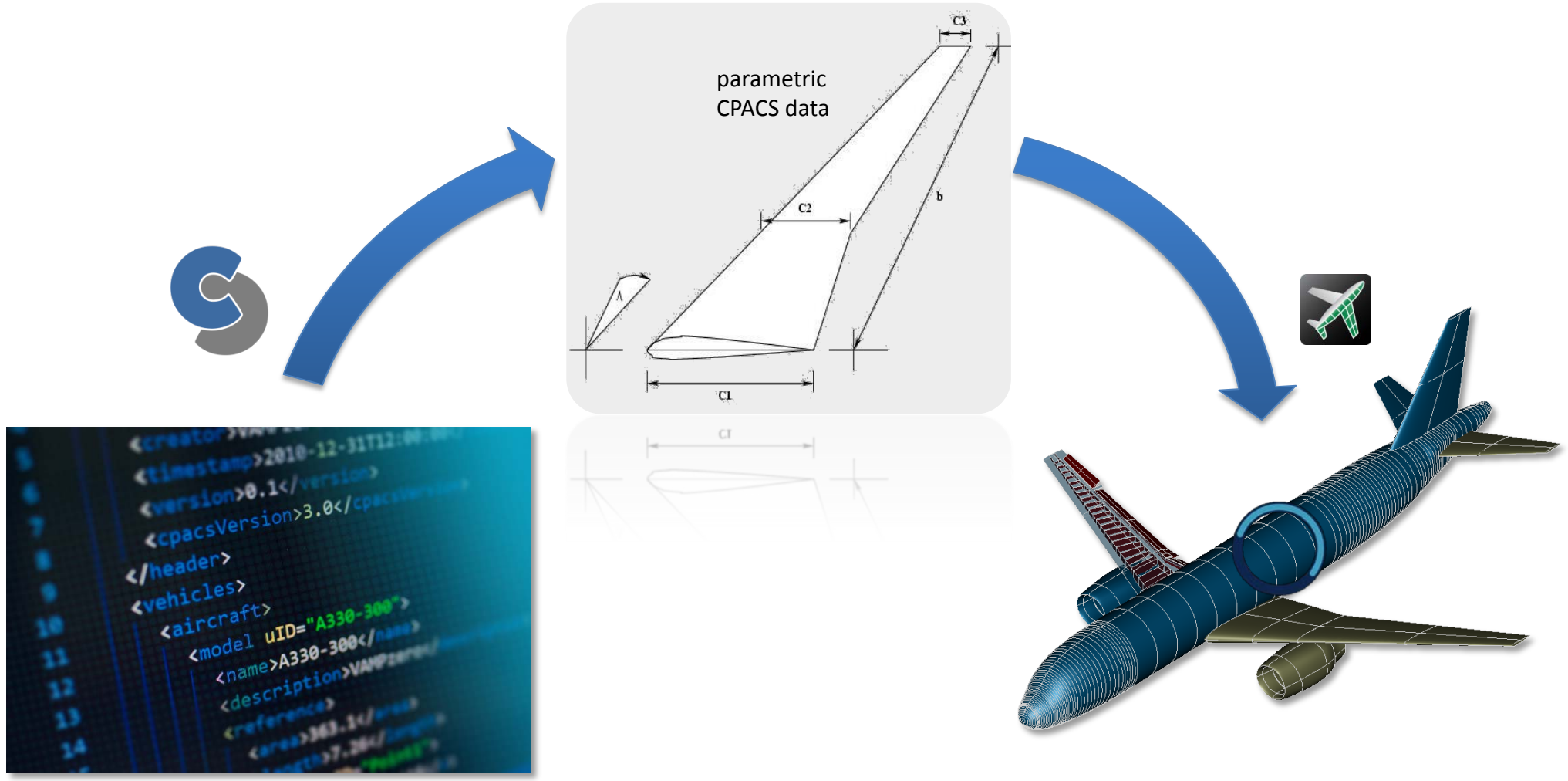
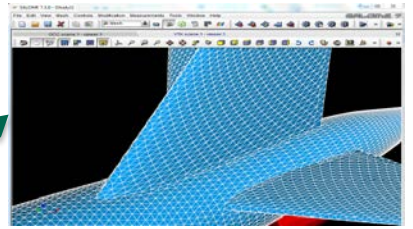
Parametric geometry

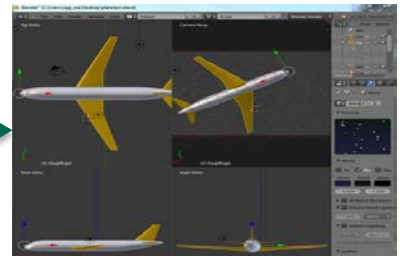


Features and Applications

- Custom geometric modeling algorithms
- Geometry export to common file formats, e.g.
  IGES, STEP, STL, VTK, Collada
- NURBS-based modelling of the main parts, e.g.
  - Wings
  - Fuselages
  - Engine covers
  - Wing structure
  - Flaps
  - Fuselage structure (at work)
- API to query
  - Points on surfaces
  - Intersections
  - Projections
- Mesh generation (at work)
  - Volume meshes for fluid dynamics simulations
  - Surface meshes for structural analysis, radar signatures

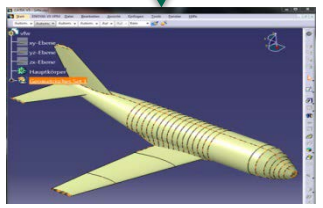


Mesh Generation for Simulations (at work)



Rendering, Visualization

3D Printing



Modeling with CAD Systems

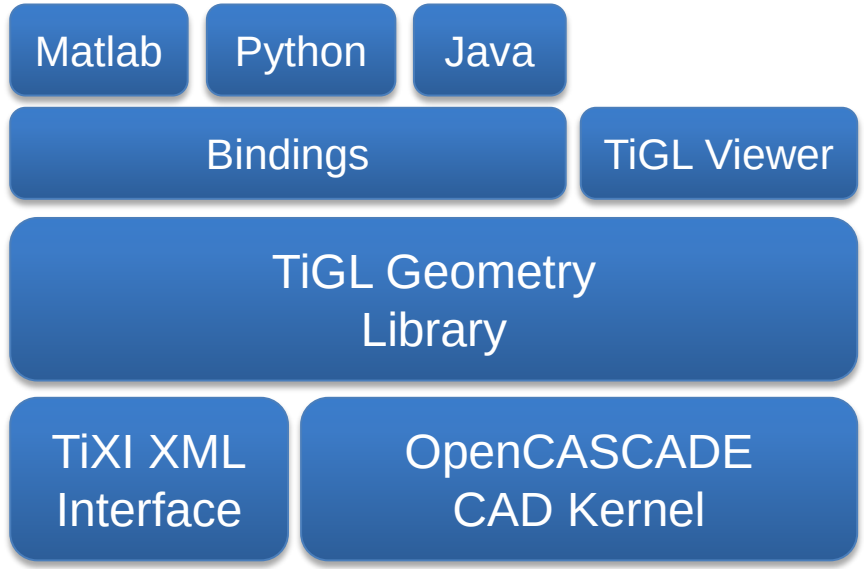
Architecture

- TiXI (https://github.com/dlr-sc/tixi)
  - Library to parse XML (CPACS) files

- OpenCASCADE (https://www.opencascade.com/)
  - Geometry (NURBS-based)
  - Topology (Boundary Representation)
  - CAD Exports, Visualization

- Language Bindings
  - Generated via SWIG (http://www.swig.org/)
  - Can access all C++ Data structures

- TiGL Viewer
  - 3D Visualization
  - Scripting
  - Debugging



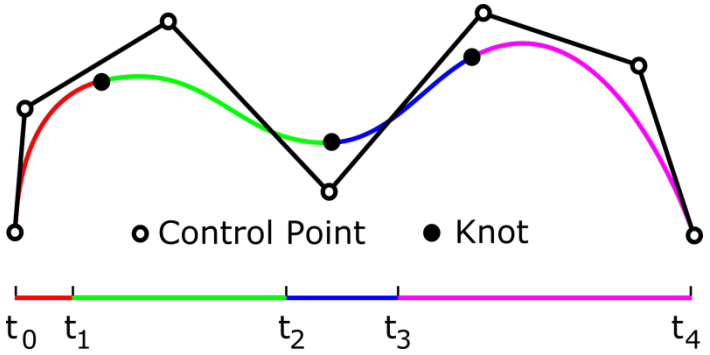
Under the hood
B-splines / NURBS

- B-spline curve:

$$\boldsymbol{c}(u) = \sum_{i=0}^{n} \boldsymbol{P}_i * N_i^d(u, \boldsymbol{t})$$

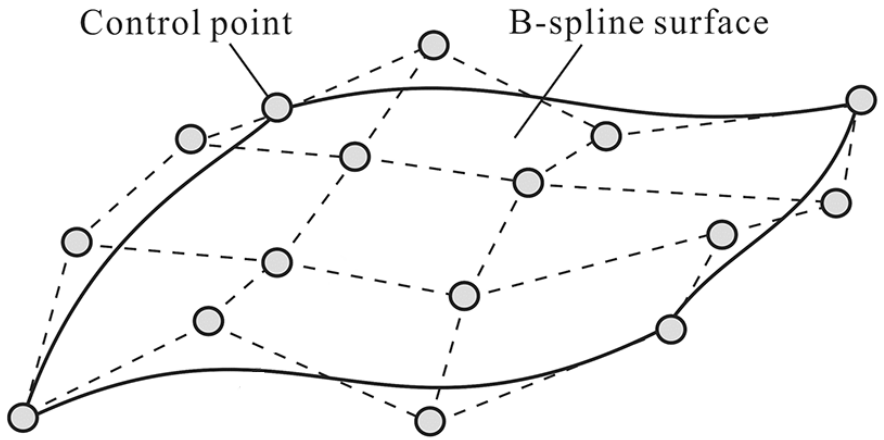
with:

- Control points $\{P_i^c\}$
- B-spline basis functions $N_i^d(u, \boldsymbol{t})$
- Knot vector $\boldsymbol{t}$, $t_i \leq t_{i+1}$



- B-spline surface:

$$\boldsymbol{s}(u, v) = \sum_{i=0}^{n} \sum_{j=0}^{m} \boldsymbol{P}_{ij} * N_i^{d_u}(u, \boldsymbol{t}_u) * N_j^{d_v}(v, \boldsymbol{t}_v)$$



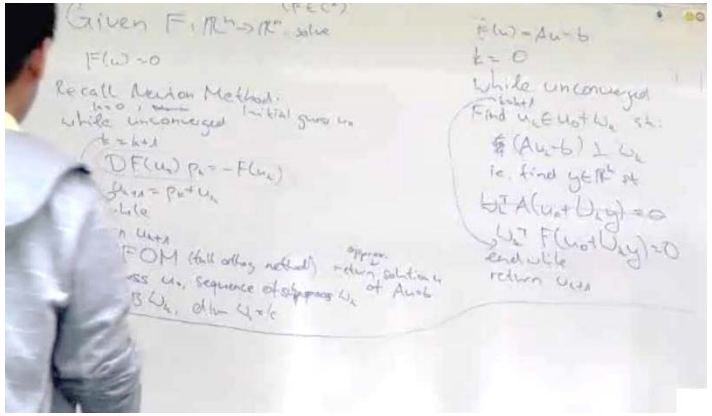
Under the hood
B-spline curve interpolation

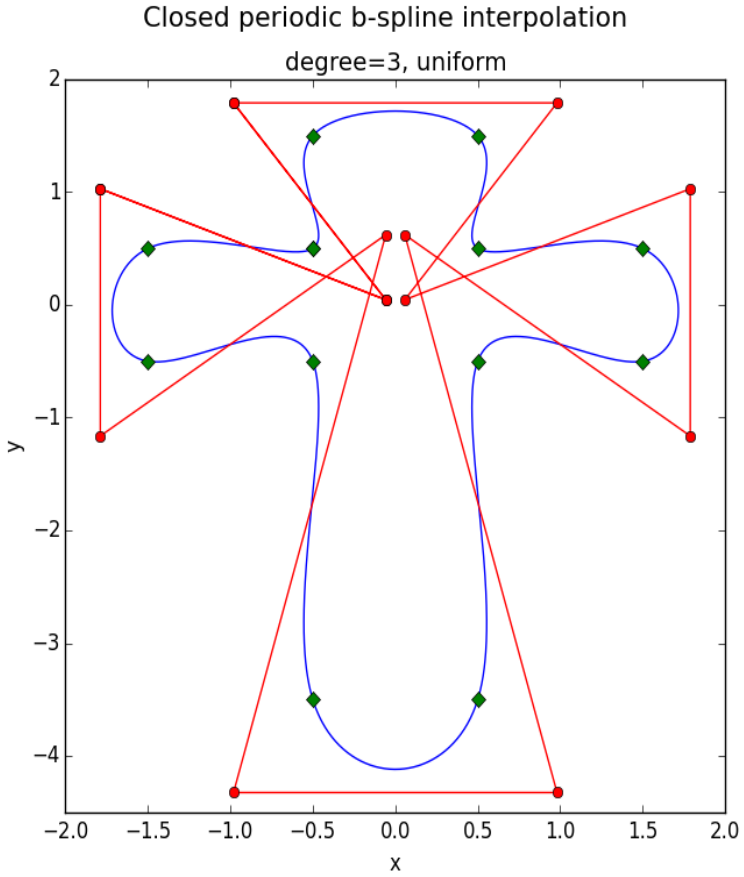
- Solve control points Pi, given data points Dj, such that:

$$\sum_{i=0}^{n} \boldsymbol{P}_i * N_i^d(u_j, \boldsymbol{t}) = D_j$$

$$\Rightarrow \boldsymbol{Np} \equiv \boldsymbol{d}$$

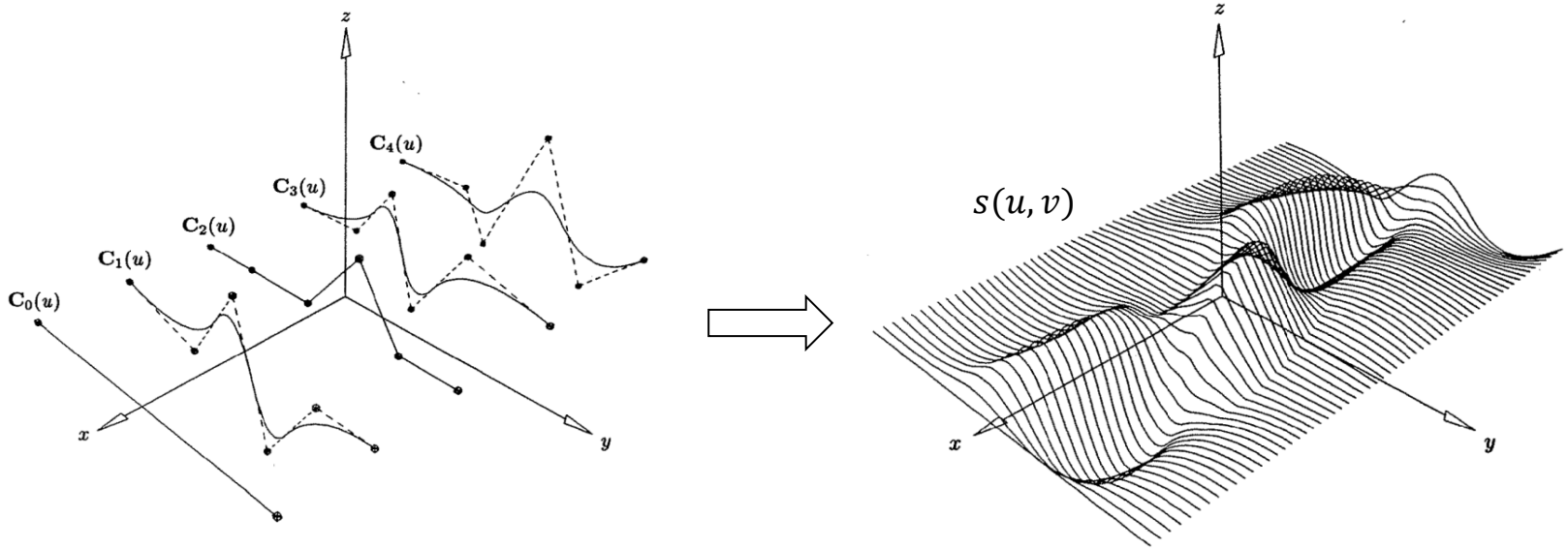
i.e. the curve passes though the data points





Under the hood
B-spline surface skinning

- Interpolates set of B-spline curves $c_i(u)$ by B-spline surface $s(u, v)$



- First: knot insertion to create same knot vector for all curves
- Then: Interpolate each row of control points with a curve → Control points of surface

Gordon Surfaces
Curve network interpolation

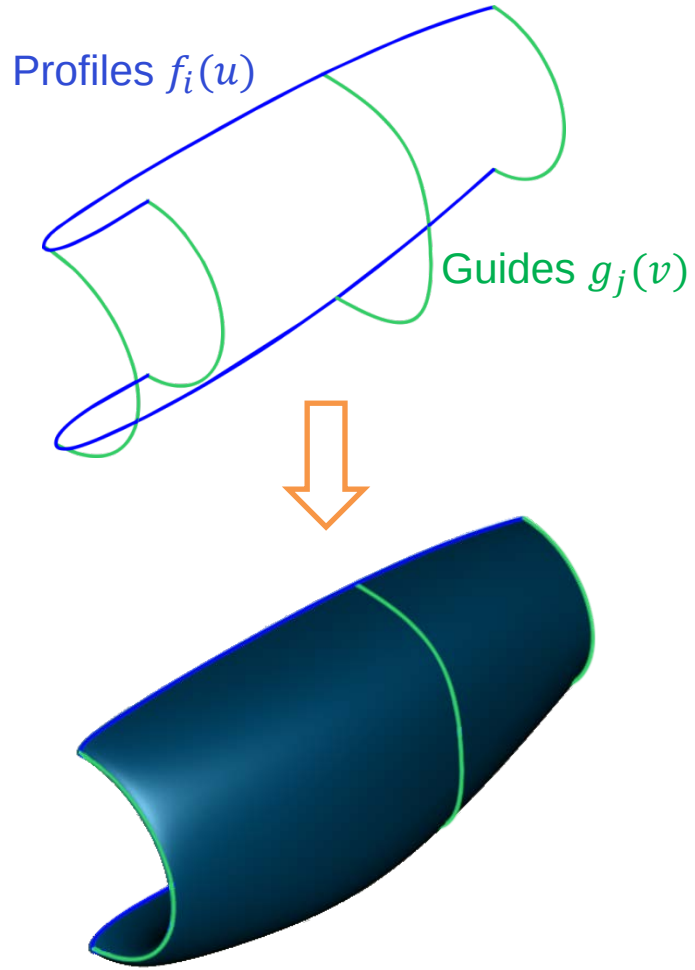
- Given network of profile and guide curves: Find surface that interpolates these curves
- Problem: No free library available for curve network interpolation!
- Custom development from OpenCASCADE for DLR based on Coons-patches showed poor results
- „Gordon Surfaces“ interpolate curve networks, but require the curves to be compatible

Compatibility condition

➢ All profile curves $f_i(u)$ must intersect with a guide curve $g_j(v)$at exactly the same parameter value u_j and vice versa:

$$f_i(u_j) = \mathrm{g_j}(\mathrm{v_i}), \forall i, j$$

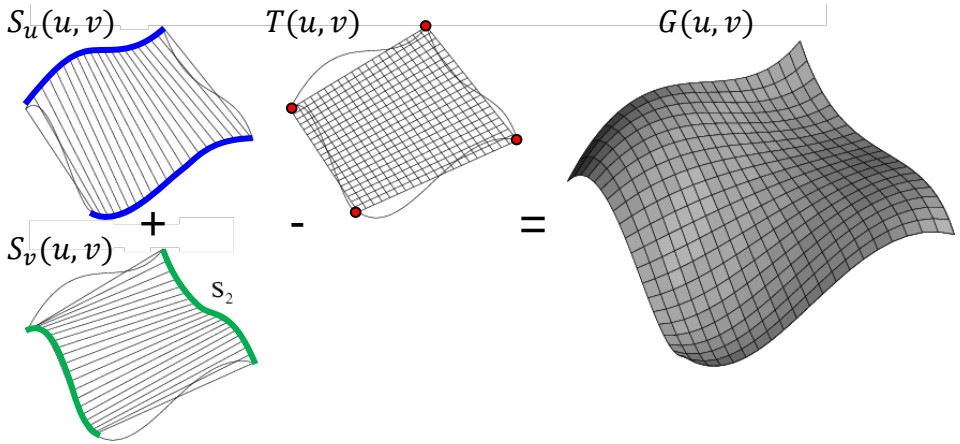
- Practically never the case → Reparametrization of the curves (tricky)



Gordon Surfaces
Algorithm overview

→ Gordon Surface is superposition of three surfaces:

$$G(u,v) = S_u(u,v) + S_v(u,v) - T(u,v)$$



$S_u(u,v)$: Skinning surface interpolating all profiles

$S_v(u,v)$: Skinning surface interpolating all guides

$T(u,v)$: Tensor product surface interpolating the intersection points of the curve network

→ Convert Gordon surface to B-Spline / NURBS for further use in TiGL
(degree elevation, knot insertion)

Gordon Surfaces
Robustness

- In theory: Profiles and guides must intersect each other!
- In practice: Allow for user defined tolerances
- Allow curve imperfections
- Reorder and reverse curves if necessary
- Try to handle ALL special cases!
- Provide Coons-based fallback solution

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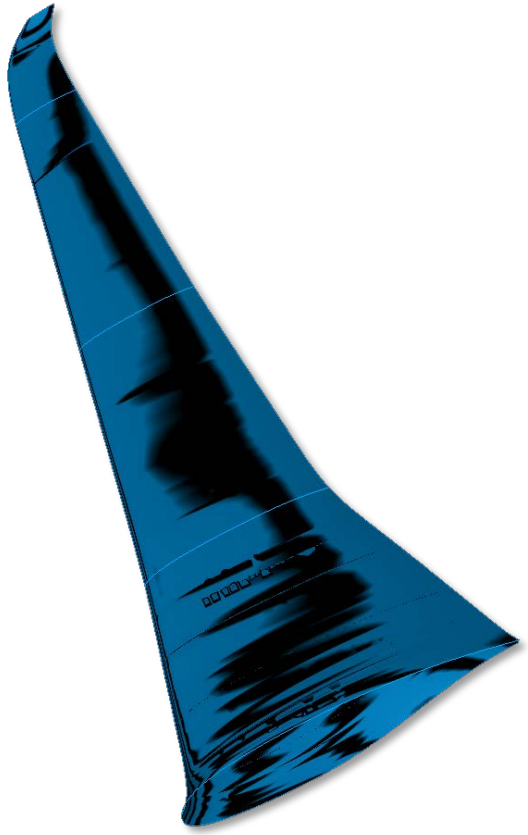
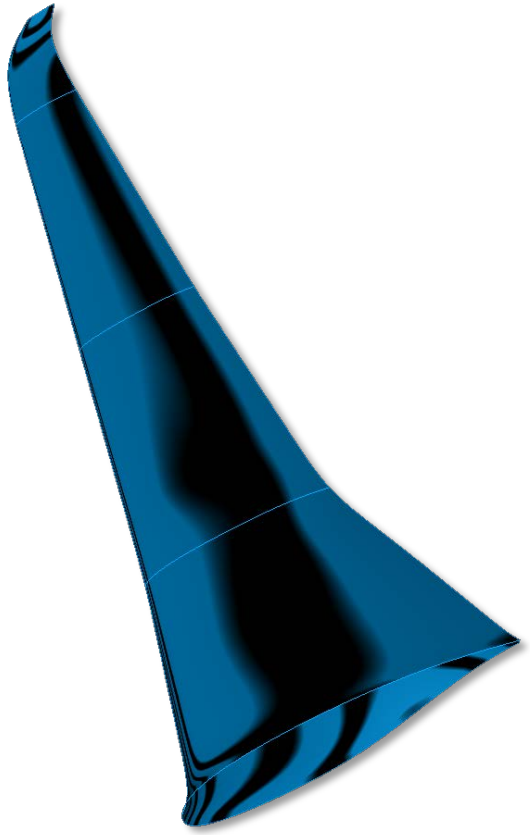
Surface Quality Analysis

- Surface quality analysis with zebra stripe plot
- Implemented in TiGL Viewer using OpenGL fragment shader code

Gordon Surface
Results: Wing

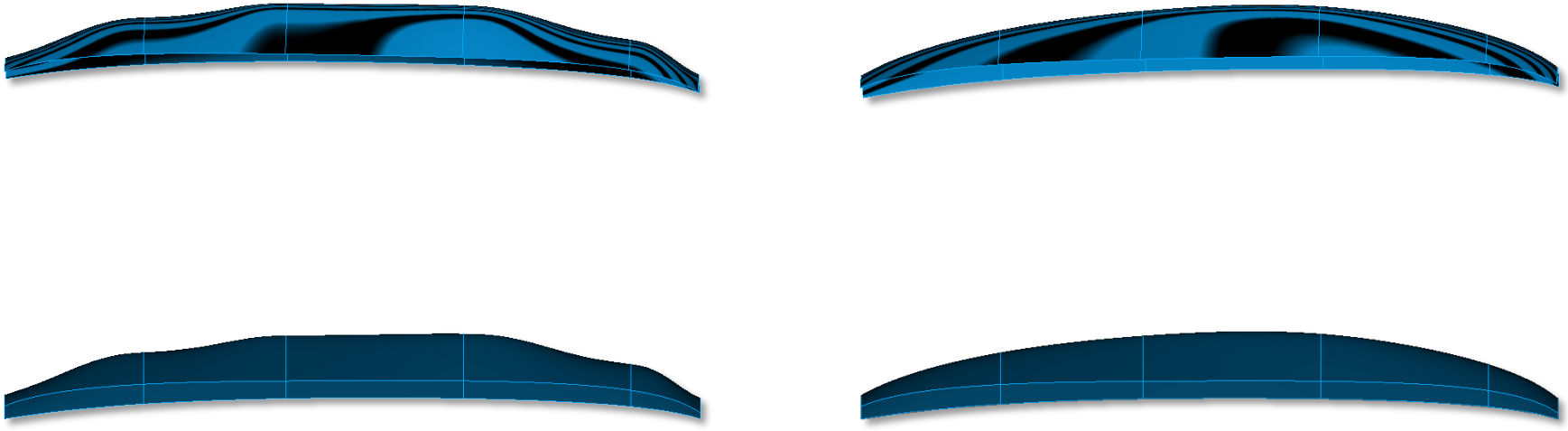


Old – Coons Style ☹️



New – Gordon Style 🙂

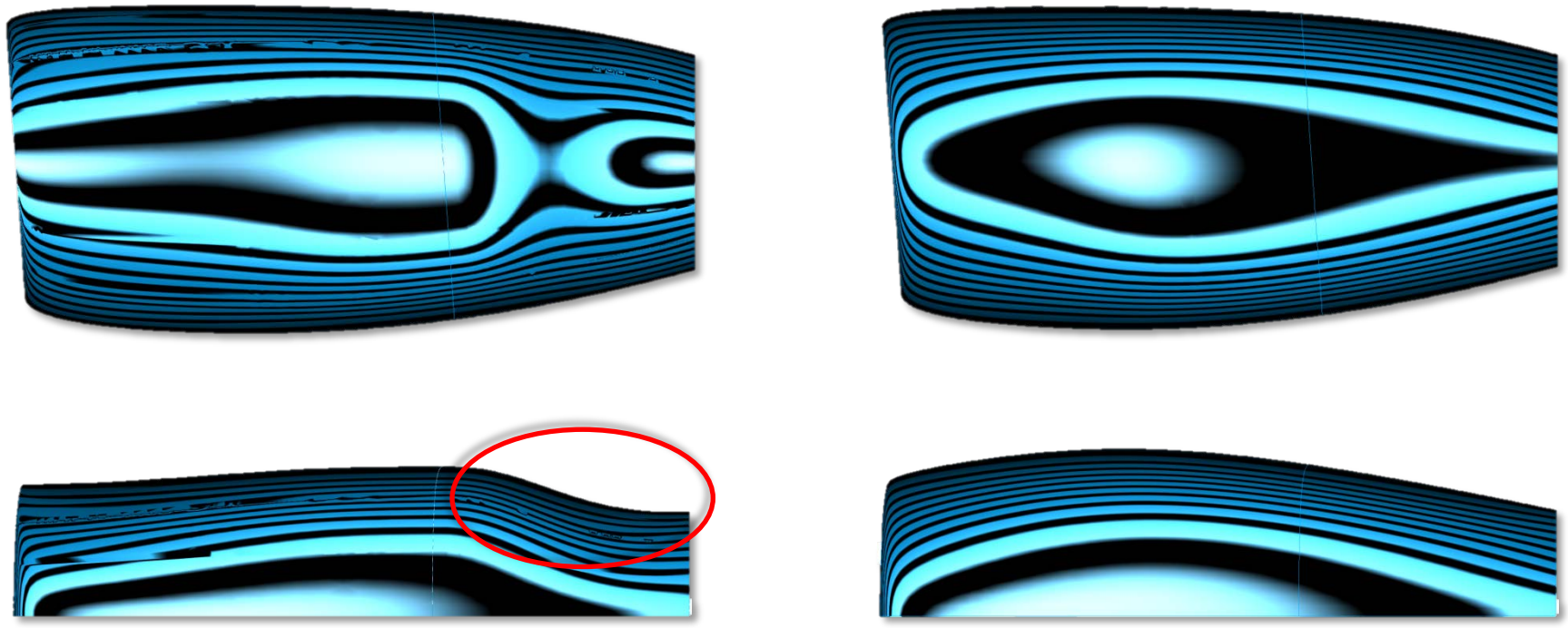
Gordon Surface
Results: Belly Fairing



Old – Coons Style ☹

New – Gordon Style 🙂

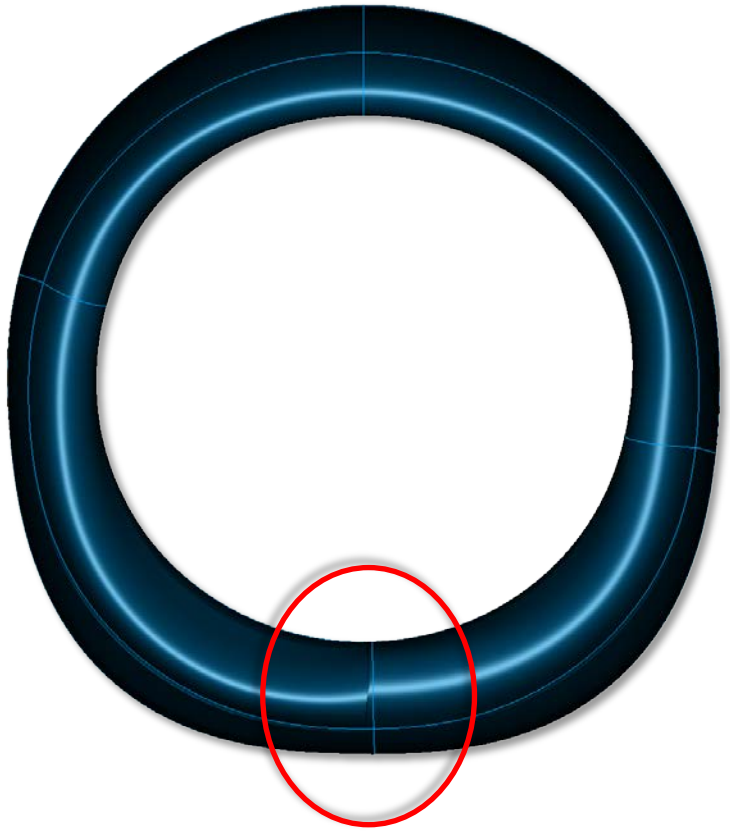
Gordon Surface
Results: Engine Cover



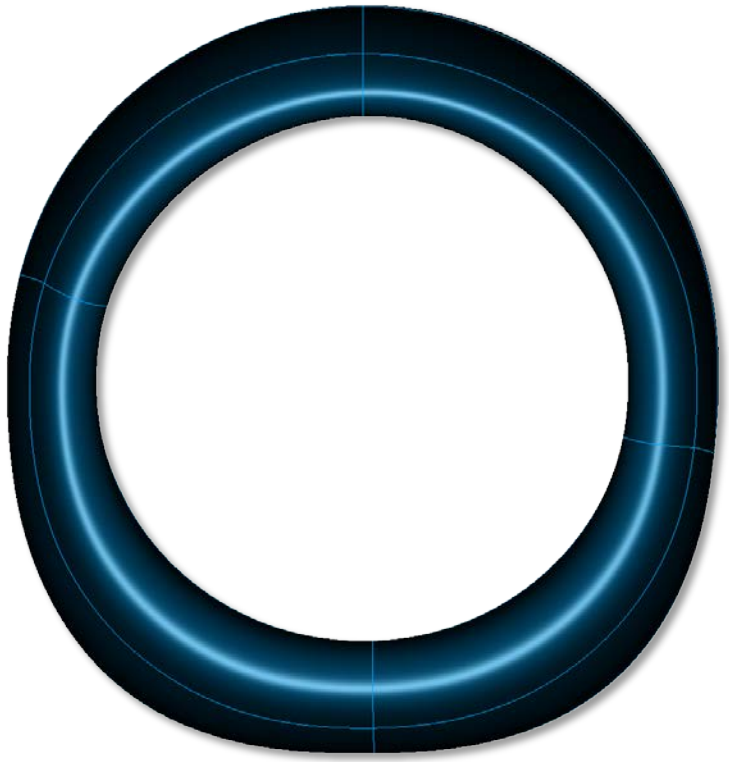
Old – Coons Style ☹

New – Gordon Style 🙂

Gordon Surface
Results: Engine Cover



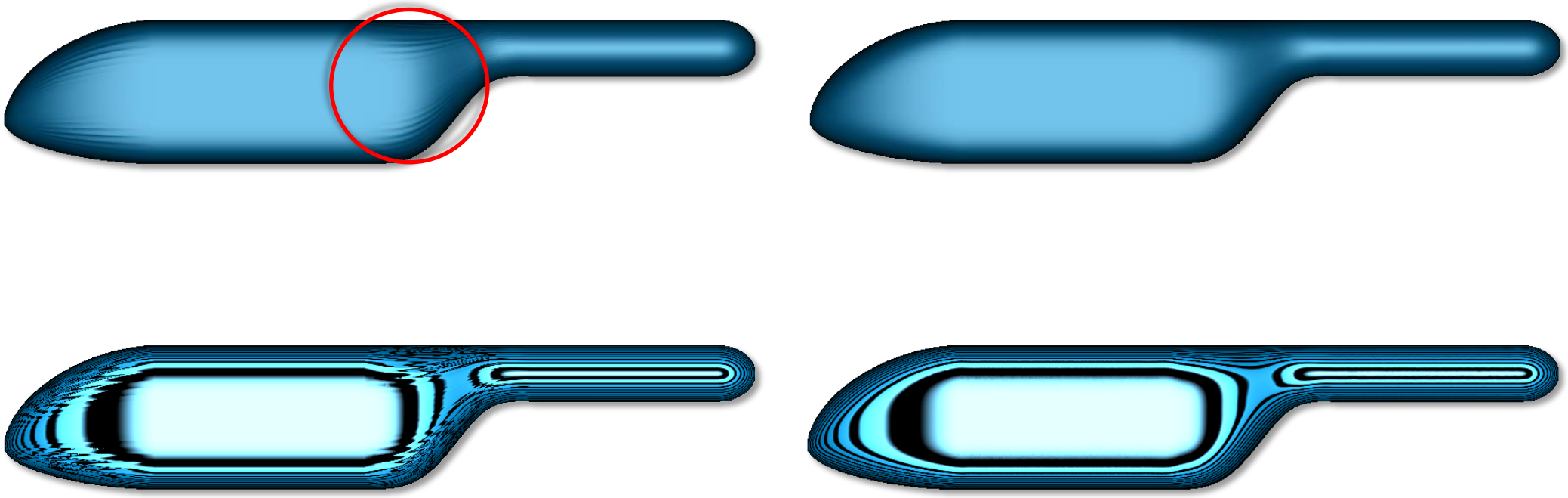
Old – Coons Style 😕



New – Gordon Style 🙂

Gordon Surface

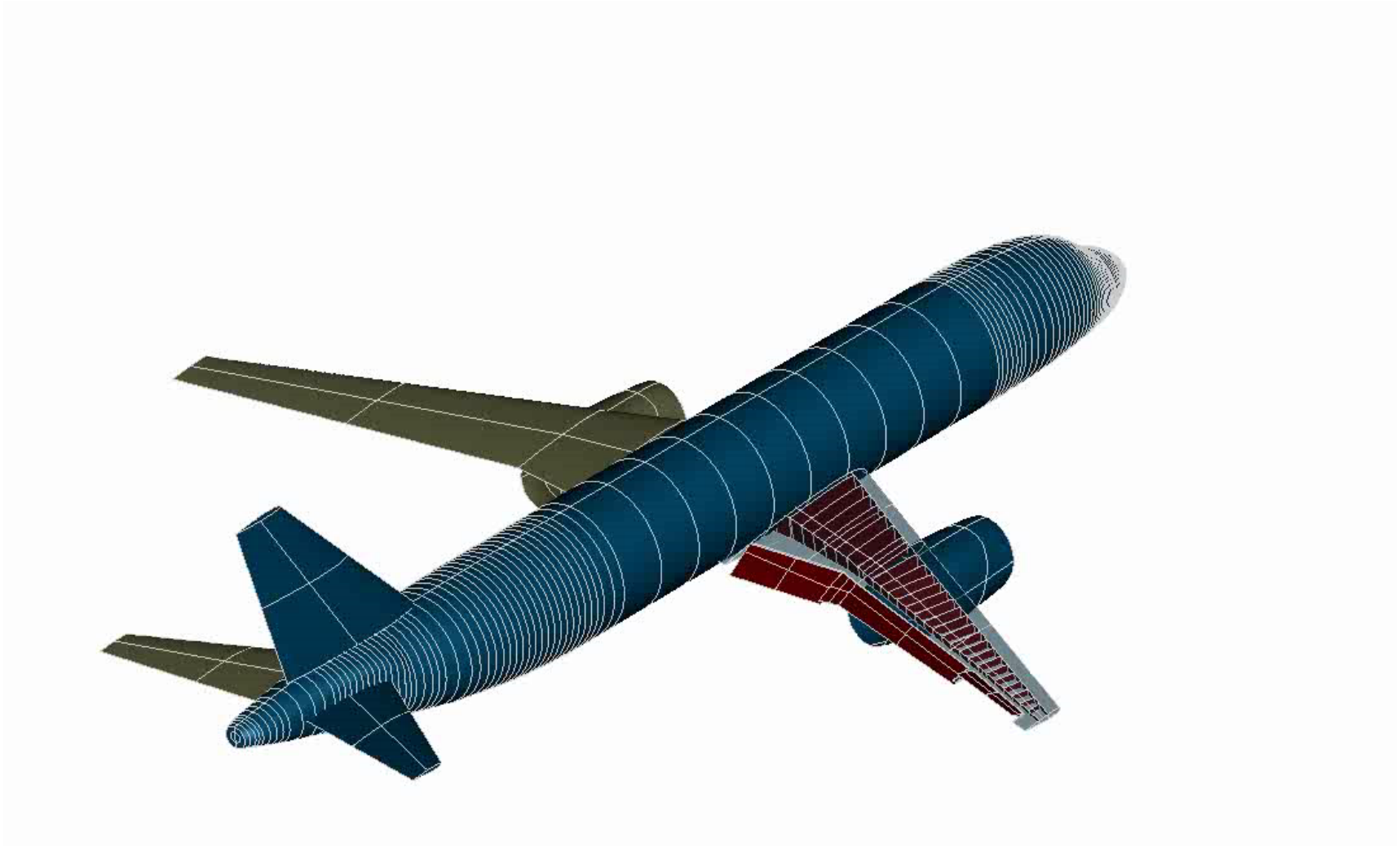
Results: Helicopter Body



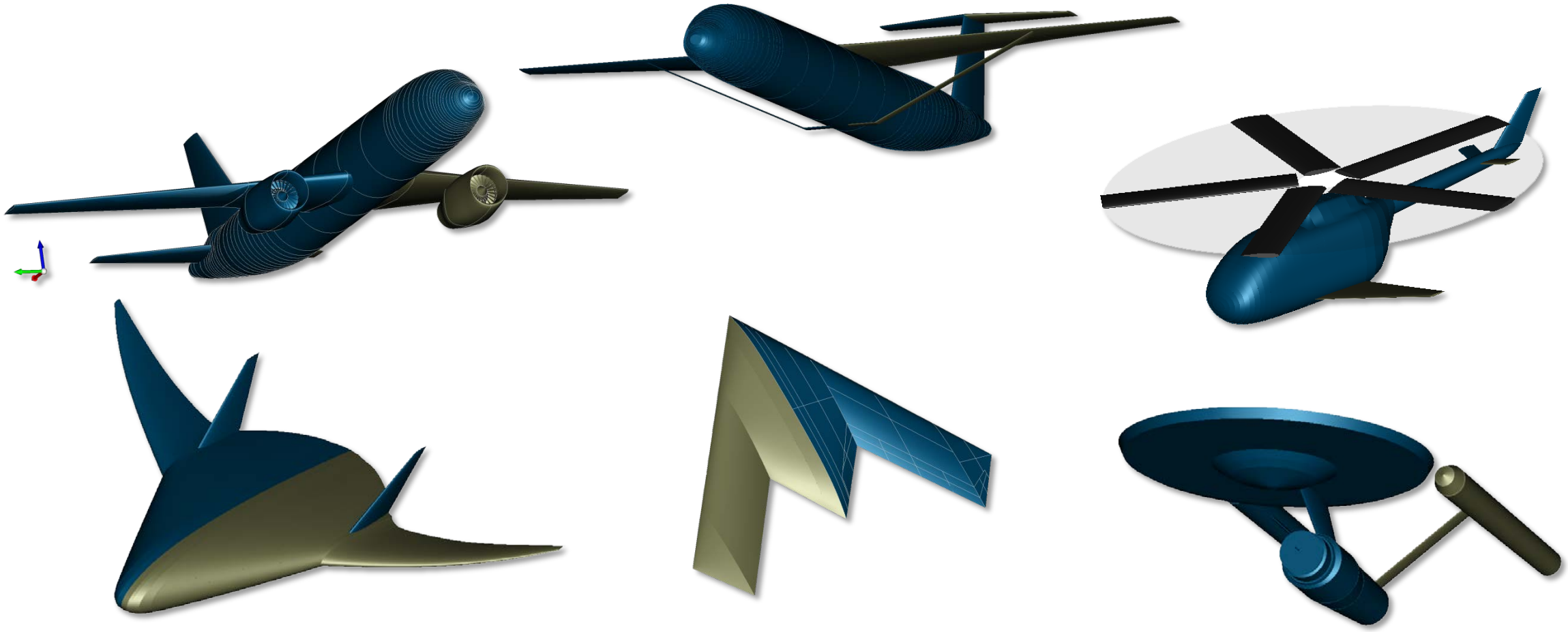
Old – Coons Style 😕

New – Gordon Style 🙂

Full aircraft model

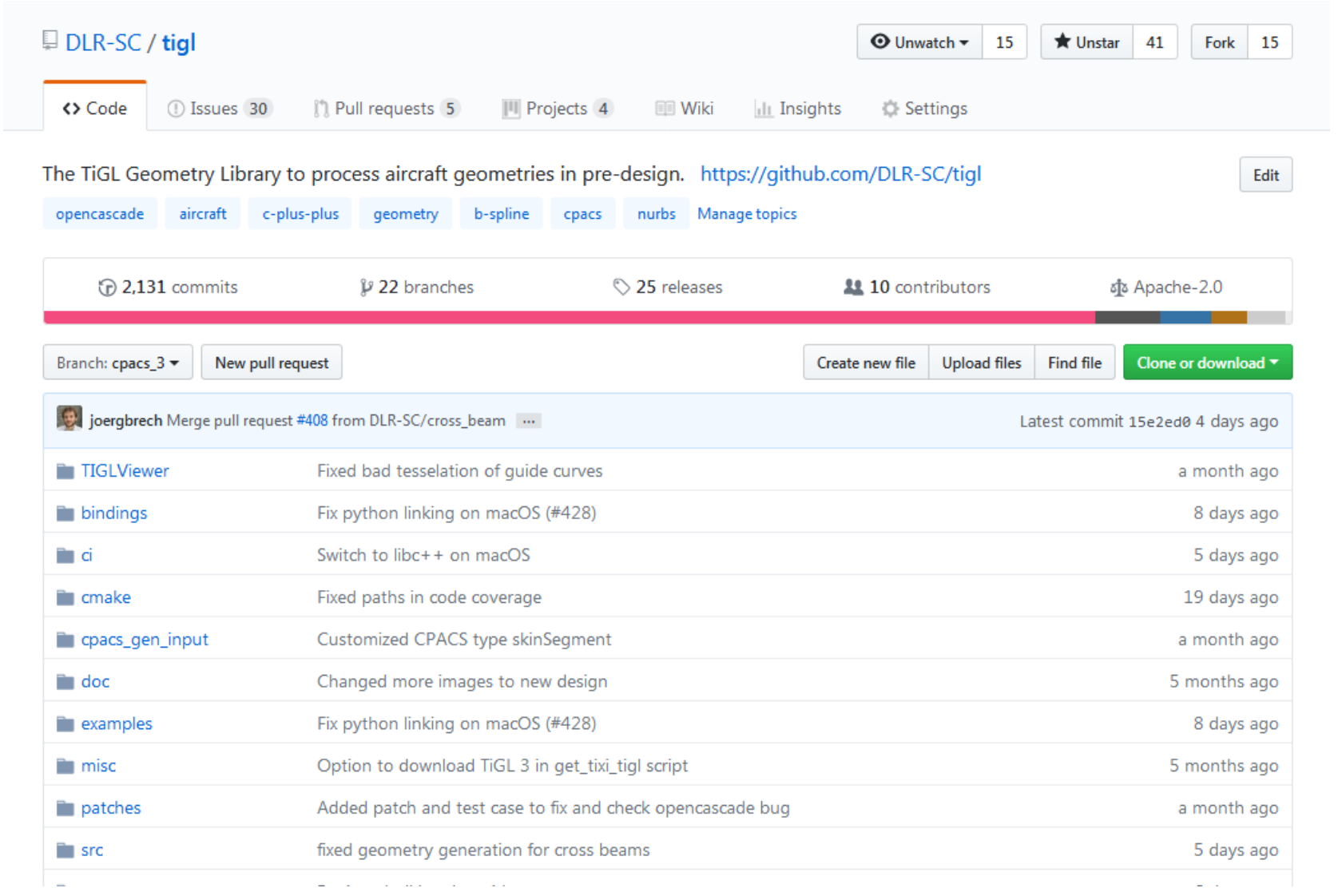


Possible aircraft designs



TiGL on GitHub

- Open Source, Apache-2.0 License
- ~ 120 kLOC
- ~43 kLOC auto-generated from CPACS XML schema
- https://github.com/DLR-SC/tigl



Conclusion

Summary

- TiGL is a library for geometric modeling of aircraft
- TiGL can be used for general purpose geometry modeling too
- Gordon Surfaces are a major building block for surfaces with high surface quality

Outlook

- Fuselage structure will come soon
- TiGL 3 Release probably in Q3 / 2018 (when CPACS 3 is finished)
- More aircraft specific geometries

Thanks to all TiGL Contributors

Sebastian Deinert (Airbus)
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Reinhold Maierl (Airbus)
Merlin Pelz (DLR)
Paul Putin (DLR)
Konstantin Rusch (DLR)
Tobias Stollenwerk (DLR)

Thank you for your attention!

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